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IMW-1

Plan for Establishment of Intensively Monitored Watersheds for Effectiveness Monitoring

Recommendation to
Washington Salmon Recovery Funding Board

Prepared by

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Introduction

The Salmon Recovery Funding Board (SRFB) and others have made substantial investments intended to benefit salmon and steelhead populations in the Pacific Northwest (SRFB 2002; GAO 2002). Although research has shown improvements in specific phases of their life history due to management actions (see Appendix X, GAO 2002), ultimately, cause-effect relationships between management actions and salmon population response must be established to assess the effectiveness of regulatory and restoration actions in restoring salmon (Botkin et al. 2000; MDT 2001; IAC 2002; ISP 2002a, 2002b). Development of an approach using Intensively Monitored Watersheds (IMWs), as described below and built upon the Salmon Index Watershed Monitoring conducted by the Washington departments of Fish and Wildlife (WDFW) and Ecology (Summers 2001; Seiler et al. 2002), is one means of studying the linkages between management actions and fish production. This project will begin to develop the infrastructure to enable the implementation of these experiments.

Intensive Watershed Monitoring

The basic premise of IMWs is that the complex relationships controlling salmon response to habitat conditions can best be understood by concentrating and integrating monitoring and research efforts at a few locations. The types of data required to evaluate the response of fish populations to management actions that affect habitat quality or quantity are difficult and expensive to collect. Focusing efforts on a relatively few locations enables enough data on physical and biological attributes of a system to be collected to develop a comprehensive understanding of the factors affecting salmon production in freshwater.

Intensive, watershed-scale research and monitoring efforts have generated results that have been very influential in the development of environmental management strategies in North America. Some of the earliest intensive monitoring efforts were instituted by the U.S. Forest Service in the 1950s to better understand hydrologic responses to logging. Efforts at these sites expanded over time to encompass chemical and biological responses as well. Changes in land use practices nationwide have been based on studies conducted at experimental watersheds like the H.J. Andrews Experimental Forest in Oregon, the Hubbard Brook Experimental Forest in New Hampshire and the Coweeta Experimental Forest in North Carolina. The success of these efforts spawned a number of intensive, watershed-level research efforts in the Pacific Northwest to evaluate the response of salmon to forest practices. The Alsea Watershed Study, which was initiated in the 1960s, evaluated the response of coho salmon and cutthroat trout to various logging methods in a series of small watersheds on the Oregon coast. Results from this study provided much of the technical rationale for the measures to protect aquatic habitat incorporated into the forest practice regulations of Oregon and Washington in the early 1970s. In the 1970s an ambitious watershed-level project was initiated at Carnation Creek on Vancouver Island, British Columbia that evaluated the response of coho and chum salmon to the logging of a previously unlogged watershed. The results of this study led to a revision of the forestry code for B.C. and also influenced revisions to forest practice rules in other areas of the Pacific Northwest. Intensive, watershed-level studies such as these form the foundation of our knowledge about the freshwater habitat requirements of salmonid fishes in the Pacific Northwest.

IMW is an efficient method of achieving the level of sampling intensity necessary to determine the response of salmon to a set of management actions. Evaluating biological responses is complicated, requiring an understanding of how various management actions interact to affect habitat conditions and how system biology responds to these habitat changes. The response of the fish is dependent on the relative availability of the habitat types it requires, which changes through the period of freshwater rearing (Table 1), and the manner in which these habitat types are influenced by application of a management action. Further complicating the issue is the fact that the relative importance of each habitat type in determining fish survival changes from year-to-year due to variations in weather and flow, the abundance of fish spawning within the watershed and other factors. For example, smolt production can be dictated by spawning habitat availability and quality during years when flood flows occur during incubation and greatly decrease egg survival (Seiler et al. in prep). However, during years of more benign flow conditions during egg incubation, population performance may be more influenced by the availability of food during spring and summer or adequate winter habitat. Untangling the various factors that determine performance of the salmon and how these factors respond to land use actions or restoration efforts can only be accomplished with an intensive monitoring approach.

Table 1. Habitat requirements of coho salmon during freshwater rearing. As outlined in this table, the changing requirements of the fish stress the need to develop monitoring designs that evaluate responses at a spatial scale large enough to encompass the full range of habitat types required by the fish to complete freshwater rearing.

Life History Stage	Habitat
Spawning and egg incubation	Gravel bedded riffles and pool tail outs in proximity of cover suitable for adult spawners (e.g., deep pools, undercut banks, debris jams)
Early fry rearing	Low velocity areas with cover in close proximity to food source. Typically associated with shallow, channel margin habitat with cover from wood and overhanging vegetation
Summer rearing	Pool habitat with cover in close proximity to food source. Typically found in low gradient channels with a pool/riffle morphology
Winter rearing	Low velocity areas with cover. Often associated with off-channel habitat on floodplains including low gradient tributaries, secondary channels and ponds

Experimental Design

The ultimate objective of most habitat restoration efforts for salmon is to increase the abundance of adult fish. As a result, the most meaningful measure of program effectiveness is the survival of the fish from adult spawning through smolting of their offspring. Because salmon use multiple habitat types during their freshwater residency, the spatial scale at which an evaluation is conducted should be large enough to encompass all the habitats required for the salmon to complete this phase of their life history. The size of the area required to capture the full range of habitats needed to complete freshwater rearing will vary by species. The basins selected are of sufficient size to encompass the habitat requirements for coho salmon, steelhead and anadromous cutthroat trout.

A before-after/reference-treatment experimental design will be used to separate treatment responses from responses due to factors unrelated to the treatments. This type of design is often is well suited to address many of questions amenable to IMW. It enhances the ability to differentiate treatment responses from responses due to variations in weather or other factors. This approach also necessitates that IMW efforts must be clustered in groups of two or more basins, with at least one serving as a reference site where no experimental treatments are implemented during the study. A calibration period prior to applying treatments is required to determine how the reference and treatment watershed compare in the key response variables prior to any habitat manipulation. The length of time required to develop this baseline will vary among watersheds. However, recent comparisons of adult salmon densities among multiple sites suggest that relative abundance is fairly consistent (Pess et al. 2002; Feist et al. in press), indicating that for this attribute a fairly short calibration period may suffice. The calibration period for sites with existing information on spawner abundance and smolt output would be much shorter than for watersheds where these data have not been collected.

Treated and untreated sites can be paired at a multiple spatial scales within the IMW design, the scale dependent on the question being addressed. In fact, reference sites for some reach-level projects could be within the basin designated for treatment. These reference sites would consist of portions of the basin comparable in initial condition to the location where a restoration action is applied but where no habitat manipulation would occur during the period of evaluation. Questions that can be addressed at this finer scale include life-history specific biological responses or physical habitat responses to management actions. For evaluations of effects at the scale of the entire basin, a comparison with a nearby basin that is not undergoing treatment is required. Therefore, the IMW approach does require sufficient management discipline to ensure that reference sites remain untreated through the duration of the study. This does not imply that any management activities in the reference watershed will compromise the integrity of the study. The validity of the study design will be maintained provided that the management activities not directly related to the restoration actions being evaluated are comparable at the reference and treated locations. For example, the effectiveness of restoration actions can be evaluated in watersheds being actively managed for wood production provided that the type and intensity of forest management activities in the treated and reference watersheds are comparable.

Candidate Basins

WDFW's current long-term smolt monitoring sites (Figure 1; Table 2) were used to identify initial candidates IMWs. Drawing upon existing resources (smolt traps) will lower the costs and shorten the startup time immensely. The precision of the smolt production estimates is known for these sites, saving much effort in finding suitable locations, installing new traps, and verifying the accuracy of the estimates. In addition, most of the existing sites have had considerable habitat work done in the watersheds which, combined with the knowledge of the biologists working there, will be invaluable in generating relevant, testable hypotheses on the factors influencing smolt production.

Each of the current long-term smolt monitoring sites (Table 1) was evaluated based on the following criteria:

1. *The basin is small enough that habitat may be effectively monitored but large enough to encompass all freshwater life stages.* Habitat monitoring is very demanding and the level of effort required is not feasible on a large scale.
2. *Current monitoring provides a precise estimate of smolt production for the entire basin above the trap*.
3. *Estimates of returning adults are available or feasible with additional effort.* Adult fish can be especially difficult to estimate. Preference was given to sites where accurate adult counts are feasible, if not currently available.

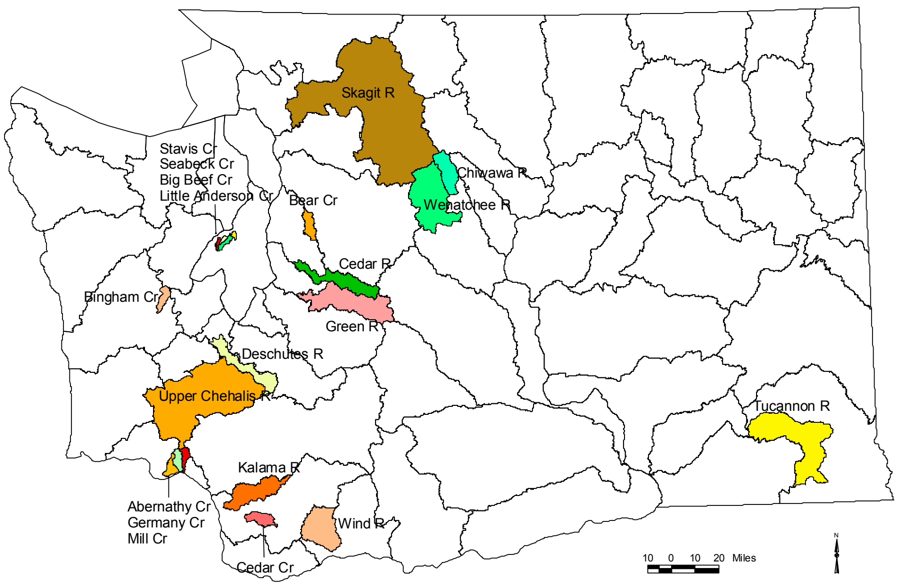

Figure 1. Map showing the watershed area above current WDFW long-term smolt traps. Skagit basin above Gorge Dam is not shown.

4. *Multiple, similar watersheds with contrasting land management are preferred.* While true experimental 'control' watersheds may not be available, insight into the relative effects of different land management or habitat restoration strategies can be evaluated by comparing basins which are similar in all respects but the management scenario.
5. *Long-term record of smolt production was preferred*. Sites with longer data records enable us to construct a history of changes in land use, climate, flow conditions, and other pertinent characteristics. This can be used with the smolt production records to build working hypotheses concerning the factors affecting smolt production.

Based on these criteria, seven basins in two different WRIAs in which smolts have been trapped were identified (Table 3; Figures 1 and 2). The four basins forming a Big Beef/Seabeck complex (BBS) are on the Kitsap Peninsula (WRIA 15), and a Germany/Mill/Abernathy complex (GMA) in the Grays-Elochoman WRIA (25) is on the lower Columbia River.

Big Beef Creek on the Kitsap peninsula has the longest data record, to the late 1970s, and includes escapement estimates (Table 4). Smolt traps have been operated on Seabeck Creek, Little Anderson Creek, and Stavis Creek since the early 1990s. These basins are similar geologically, topographically, and in land use history, but differ in the degree of development and current forest management. Because of this, suitable treatment-reference study designs are possible.

Table 2. Trap site location for currently monitored wild anadromous salmonid smolt monitoring index watersheds.

WRIA	Trap Site/Watershed	Area (acres)	Species
03/04 Skagit R	Skagit River	1223321	Chinook, coho, pink, steelhead, bull trout
08 Cedar R	Bear Creek	27886	Chinook, coho, steelhead, cutthroat, sockeye fry
	Cedar River	109286	Chinook, coho, steelhead, cutthroat, sockeye fry
O9 Green/Duwamish	Green River	207959	Chinook, coho, steelhead
13 Deschutes	Deschutes River	121876	Coho
15 Kitsap	Big Beef Creek	9044	Coho, steelhead
	Little Anderson Cr.	3173	Coho, steelhead
	Seabeck Creek	3471	Coho, steelhead
	Stavis Creek	3872	Coho, steelhead
22 Lower Chehalis	Bingham Creek	22045	Coho, steelhead, cutthroat
23 Upper Chehalis	Chehalis River	611521	Coho
25 Grays Elochoman	Mill Creek	18648	Chinook, coho, steelhead, cutthroat
	Germany Creek	14471	Chinook, coho, steelhead, cutthroat
	Abernathy Creek	18309	Chinook, coho, steelhead, cutthroat
27 Kalama R	Kalama River	113793	?
	Cedar Creek	33935	?
29 Wind R	Wind River	135965	?
35 Middle Snake	Tucannon River	310725	?
45 Wenatchee	Wenatchee River	234180	?
	Chiwawa River	60575	?

Abernathy Creek, Germany Creek, and Mill Creek, tributaries to the lower Columbia River (RM 53-56), were selected in spite of the short duration of smolt sampling (established in 2001). These basins provide good estimates of multiple species, have similar land use, but under distinctly different land management schemes and a mix of large and small private owners and public lands (Tables 3 and 4).

Table 3. Land cover, land management, and ownership percentages for each trap basin are shown below. Land cover is based on satellite imagery from the early 1990s. HCP area is based on 2001 maps provided by U.S. Fish and Wildlife Service. The land under Forest and Fish rules (FFR) is based on a map compiled for DNR and does not include small forest landowners. Public ownership was based on the Major Public Lands map, remaining land was assumed to be private.

WRIA 15 Kitsap							
Smolt trap	Basin area (acres)	Land cover (%)		Land mgt (%)		Ownership (%)	
		Forested	Developed	FFR	HCP	Public	Private
L. Anderson Cr	3173	87	8	6	4	12	88
Big Beef Cr	9044	90	3	43	24	28	72
Seabeck Cr	3471	91	2	25	20	19	81
Stavis Cr	3872	83	2	37	39	17	83
WRIA 25 Grays-Elochoman							
Mill Cr	18648	94	0	23	55	61	39
Germany Cr	18309	92	0	44	35	35	65
Abernathy Cr	14471	85	0	83	0	0	100

Table 4. Period of record and data collected at each smolt trap.

WRIA 15 Kitsap					
Smolt trap	Watershed analysis?	Juveniles		Adults	
		Since	Species	Since	Species
Anderson Cr	Yes, 1998	1992	coho	-	
Big Beef Cr	Yes, 1998	1978	coho, cutthroat, steelhead	1976	chinook, chum, coho
Seabeck Cr	Yes, 1998	1993	coho	-	
Stavis Cr	Yes, 1998	1993	coho	-	
WRIA 25 Grays-Elochoman					
Mill Cr	No	2001	chinook, coho, cutthroat, steelhead	-	
Germany Cr	No	2001	chinook, coho, cutthroat, steelhead	-	
Abernathy Cr	No	2001	chinook, coho, cutthroat, steelhead	-	

Basin Descriptions

Big Beef/Seabeck Complex

These four basins, located on the west side of the Kitsap Peninsula, comprise a large portion of the West Kitsap Watershed Administrative Unit (WAU). This WAU is within the Puget Sound trough, which has experienced considerable glacial activity in its geological history. As a result, the West Kitsap WAU generally has a gently rolling upland of glacial till with steep-sided ravines leading down to the river floodplains. The glacial till of the uplands is fairly resistant to erosion but the loose sandy soil and layers of fine textured material comprising the ravine sideslopes is much more prone to erosion. In addition, layers of clay in the ravine walls can transport water laterally and where this intersects a road cut, ground water can be expected to flow onto the road. Inputs of fine sediments were rated as a moderate to high hazard for all four creeks and roads adjacent to or draining into streams were identified as the highest contributors of fines to the stream network (W Kitsap WSA 1998).

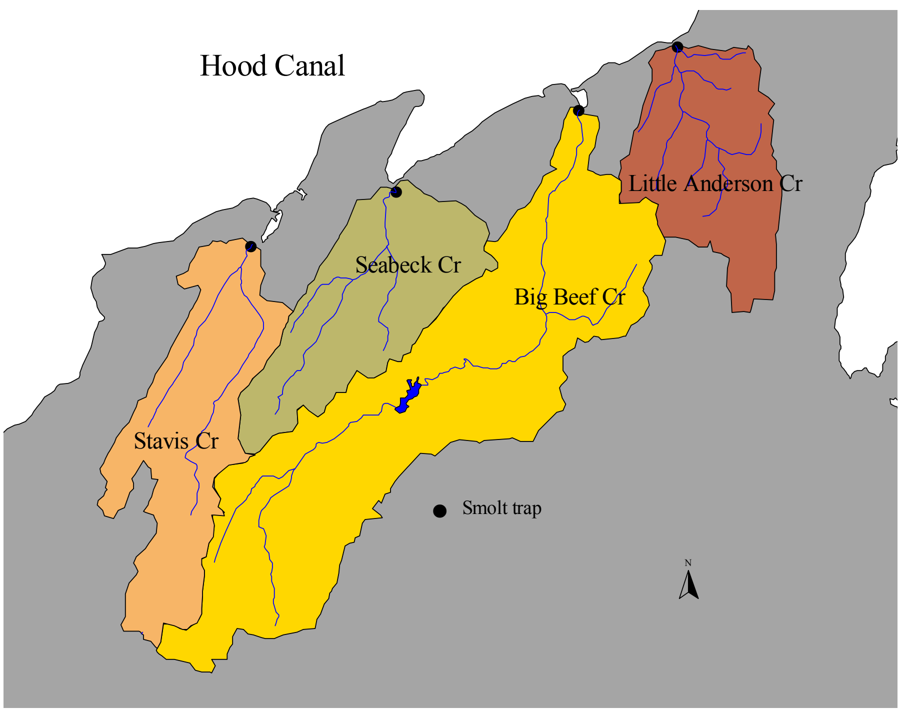

Figure 2. Location of four smolt traps in WRIA 15 (Kitsap) provides excellent estimates for coho and steelhead. Basin areas range from ~3200 to 9000 acres.

Commercial logging of lowland areas was in practice by 1870 with the establishment of large sawmills. Extensive logging of the uplands began in the 1920s when a railroad network was built to transport the timber and continued into the 1940s until few merchantable trees were left. Although forest practices have improved markedly, legacy effects may exist. Since the 1970s rural residential development has increased and continues today. Based on early 1990s satellite imagery, over 80% of each basin is forested and the proportion developed is low (Table 3). However, rural residential development has increased markedly since the 1970s and is likely degrading habitat through riparian vegetation removal, stormwater runoff, fish passage barriers, and high sediment loads (W Kitsap WSA 1998; Seiler et al. 2002)

Germany/Mill/Abernathy Complex

The GMA monitoring complex is located on the Lower Columbia River downstream of Longview, Washington. Watershed areas above the smolt trap are similar (Table 3) ranging from 14,400 to 18,700 acres. Abernathy and Germany Creeks drain steep basins with headwater elevations of up to 806-m. Mill Creek is a lower elevation basin with headwater elevations of 555-m. Land cover is largely forested with land use in all three basins focused on timber production. Abernathy and Germany Creeks are primarily comprised of private timberlands, whereas DNR owns a large share of the Mill Creek watershed. Residential and agricultural development is light and concentrated in the lower portion of all three basins. Juvenile chinook, and coho salmon and cutthroat and steelhead trout are have trapped since 2001 but adult escapement is not monitored.

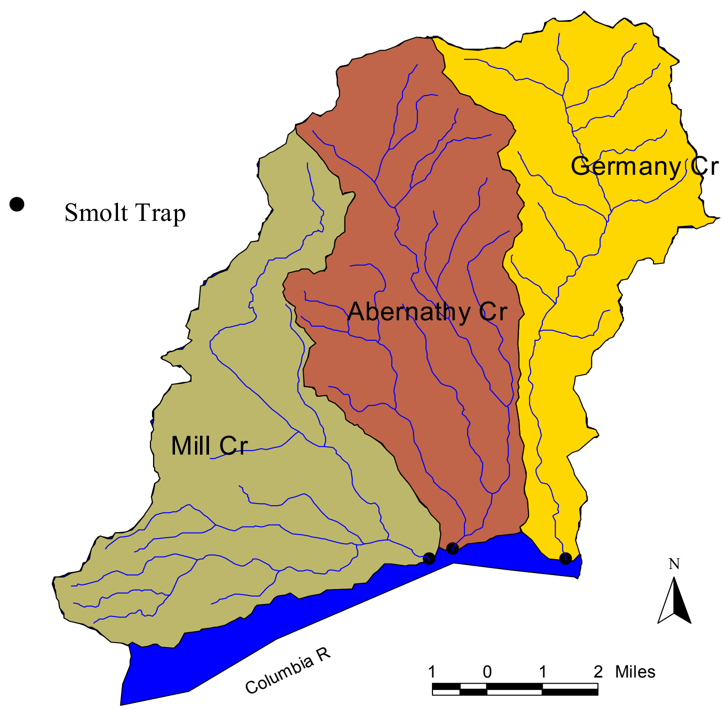

Figure 3. Location of traps on Germany, Mill, and Abernathy creeks provide very good estimates for chinook, coho, cutthroat, and steelhead.

Factors Limiting Freshwater Production

Big Beef/Seabeck Complex

Big Beef Creek

Of the four streams, Big Beef Creek is the largest, draining a 36-km^2 basin (Table 5). Big Beef Creek is also unique in that it flows through a number of depressional wetland marshes in its upper watershed. Wetland habitats are also found in the headwaters of Seabeck and Stavis Creeks, but represent a much less prominent feature in these watersheds compared to Big Beef Creek.

Big Beef Creek is also unique in that it flows through Lake Symington, a shallow, man-made reservoir surrounded by a housing development that is located in the middle of the basin. A fishway provides access for adult and juvenile coho, steelhead, and cutthroat above the dam. Downstream of the reservoir, Big Beef Creek cuts down through a canyon to reach Hood Canal. Anadromous salmonids spawning downstream of the dam include coho, chum, steelhead, and cutthroat, whereas only coho, steelhead, and cutthroat utilize the habitats above the dam.

The University of Washington Big Beef Creek Research Station is located at the mouth of the stream. The facility includes a weir, where WDFW built and currently operates an upstream/downstream trapping facility to count salmon as ascending adults and the subsequent downstream juvenile migration. The trapping facility has been operating since 1976.

Big Beef Creek has been much studied over the years. Besides long-term freshwater production monitoring, spawning ground surveys have been conducted to define the distribution of coho spawners and to recover coded wire tags. In addition, WDFW, the Point No Point Treaty Council, and the U.S. Fish and Wildlife Service have conducted habitat surveys in Big Beef Creek. From this work, project proponents from WDFW have developed a number of hypotheses as to factors that limit production of coho salmon in the basin. These factors are discussed for the three sections of Big Beef Creek: the upper watershed (above Lake Symington), Lake Symington, and lower Big Beef Creek.

<u>Upper Watershed</u> Above Lake Symington, Big Beef Creek flows through a series of depressional wetland marshes. These wetland habitats provide year around rearing habitat for coho, steelhead, and cutthroat, and are extremely important for preserving the productivity of coho in the basin. Fall flows that limit spawner access into the upper watershed reduce smolt production in the subsequent brood. In addition, the hydrologic functioning of the wetlands is threatened by development in the upper watershed. Forested lands adjacent to the wetlands are increasingly being converted to hobby farms. Increased runoff during the winter and nutrient enrichment from animal wastes resulting from conversion is degrading the suitability of the wetlands as coho habitat over time.

Table 5. Average wild coho and steelhead smolt production and productivity for the Big Beef/Seabeck (BBS) complex (1992-2002) and Germany/Mill/Abernathy (GMA) complex (2001-2002).

Stream	Average Smolt Production		Watershed	Average Smolts/km2	
	Coho	**Steelhead**	**Area (km^2)**	**Coho**	**Steelhead**
BBS Complex					
Big Beef Creek	23,443	1,528	36.0	651	42
Little Anderson Creek	263	43	12.0	22	4
Seabeck Creek	1,313	27	13.3	99	2
Stavis Creek	5,239	74	13.1	400	6
GMA Complex					
Germany Creek	7,579	7,550	58.3	130	130
Mill Creek	7,912	1,480	75.4	105	20
Abernathy Creek	6,596	7,995	74.3	89	108
Note: Coho and steelhead production estimates for the BBS complex, shown here, represent average smolt trap catches. The actual average production is slightly higher due to unaccounted for migration occurring prior to and following trap operation. Estimates for GMA complex streams represent the average total migrations of coho and steelhead smolts.					

Lake Symington Juvenile salmonids migrating out of the upper watershed must pass through Lake Symington before reaching Hood Canal. The lake is also used for coho over-wintering. Coho predation is likely considerable due to the population of large mouth bass that inhabits the lake. Water temperatures in the lake limit salmonid use during the summer months. Stream temperatures just downstream from the dam have exceeded 26C during the summer months. In 2001, water temperature exceeded the water quality standard of 16C over 44% of the time (Summers 2001). Elevated water temperature were noted for 2000' below the lake, however, the watershed analysis (W Kitsap WSA, 1998) concluded that because of the relatively good canopy cover and groundwater influence, high water temperature was not a widespread problem (Table 6).

Lower Big Beef Creek Lower Big Beef Creek is approximately 8.5-km long. The stream flows through a confined canyon for approximately 3.5-km. Further downstream it becomes less confined and opens into an alluvial valley in the lower 3-km of stream. Summer stream flow in lower Big Beef Creek is very low for a basin of its size. Summer low flows average approximately 3-cfs. Similar summer low flow levels were recorded in nearby Devil's Hole Creek on the Bangor Navy Base, which is only 1/5th its size (Volkhardt et al. 2000). Possible causes for the relatively low flow levels include:

1. Evaporation from Lake Symington and the upper watershed marshes,

2. Well withdrawals from development in the Big Beef Creek watershed and adjacent watersheds that are hydrologically connected,

3. The existence of a shallow impervious layer in the upper watershed that infiltrates little water to contribute to summer flows, and

4. The excessive accumulation of coarse sediment in the lower Big Beef Creek channel.

Table 6. Percent riparian canopy closure estimate from aerial photos (from Table D-1, W Kitsap WSA).

Basin	<70%	70-90%	>90%
Stavis Cr	8	43	50
Seabeck Cr	20	55	25
Big Beef Cr	34	40	26
Little Anderson Creek	8	46	46

Sediment recruitment to lower Big Beef Creek occurs from bank erosion and past logging/road building practices. Bank erosions rates average approximately 1.2-m^2 of eroded bank for every meter of stream length in the first 4.4-km below the dam (WDFW unpublished data). Sediment inputs from poor road construction practices are particularly noticeable on Kid Haven Road. The road was built down a right bank tributary of Big Beef Creek, forcing the tributary into the drainage ditch along the side of the road. The stream eroded the toe of the road cut during subsequent winter storms, sending thousands of yards of coarse material into Big Beef Creek.

Ames et al. (2000) describe the importance of flows during the spawning and incubation periods for the success of summer chum production. They attribute the inability of summer chum salmon populations to recover from recent-year peak flow impacts as due to a loss of resiliency in freshwater habitats that have resulted from poor land-use practices. Factors contributing to the loss of habitat resiliency in Big Beef Creek include removal of large woody debris (LWD) from the stream, removal of streamside vegetation (Table 7), loss of floodplain connectedness, and water withdrawals.

Little Anderson Creek

Little Anderson Creek is an independent tributary to Hood Canal located approximately 2-km east of Big Beef Creek in the adjacent watershed. The Little Anderson Creek watershed has an area of approximately 12-km^2. It is bordered on the east by the City of Silverdale and a part of the watershed is within the urban growth boundary of the city. Little Anderson Creek is primarily used by coho, chum, and cutthroat. A few steelhead also spawn in the stream each year.

Most of Little Anderson Creek and its tributaries are deeply incised into the steep surrounding hills. The stream gradients within the fish-bearing portions of Little Anderson Creek are high, averaging 3.1% (WDFW unpublished data). Because of the steepness of the stream channel and surrounding hillslopes, the stream is sensitive to land-use activities that increase the rate of water input to the channel, such as the creation of impervious surfaces. These conditions produce substantial stream energy during storm flow events. Stream banks are largely intact within the Little Anderson Creek watershed. Bank erosion rates average less than 0.3-m^2 of bank erosion per linear meter of stream. However, bed scour has resulted in the transport of large amounts of sediment downstream. Only low to moderate levels of instream wood are available to trap sediments and slow storm flows (WDFW unpublished data).

Table 7. Current LWD and LWD recruitment potential ratings presented as a percentage of total stream length in each category (modified from Table D-1, W Kitsap WSA).

Basin	Current LWD		LWD recruitment potential	
	On target	Off target	Good	Fair-poor
Stavis Cr	85	13	52	48
Seabeck Cr	61	39	56	44
Big Beef Cr	46	23	23	77*
Little Anderson Creek	43	55	40	60

*21% of stream length is bordered by natural wetlands, which could not support large trees and 10% due to land clearing for residential development.

Anderson Hill Road crosses the stream about one kilometer upstream of the mouth. The culvert under this road was undersized and resulted in an accumulation of sediments downstream of the culvert. Over the years, the culvert became partially blocked with sediment. During a large storm event in 1994, the partially blocked culvert dammed water upstream of the road crossing. The resulting pressure caused a new stream channel to be cut downstream of the culvert, which released thousands of yards of material and buried several vehicles. Deposition of the material downstream of the road crossing created a braided section of channel that is still in the process of recovering. In 2002, the culvert was removed and a bridge was installed in its place.

Because of the steepness of the watershed, Little Anderson Creek was probably never a very productive stream for coho salmon. Its sensitivity to bed movement likely results in high mortality during the coho winter incubation phase. Increasing development in the basin has exacerbated this problem; consequently, coho production has been reduced to as few as 43 smolts in recent years (WDFW unpublished data). The eggs laid by spring spawning anadromous cutthroat are less impacted by high stream flows. They perform better in this basin, averaging over 600 smolts per year.

Seabeck Creek

Seabeck Creek is a 13.3-km^2 watershed located approximately 4-km west of Big Beef Creek. The fish-bearing portion of the mainstem (summer) is approximately 5-km long with the lower 3-km flowing through an unconfined or moderately confined valley. In the upper 2-km, the channel is more confined and is incised within the steep surrounding hills. In addition to the mainstem, Seabeck Creek has two right-bank fish bearing tributaries (WDFW unpublished data). The smaller of these enter Seabeck Creek approximately 150-m upstream of the mouth, whereas the larger enters the creek approximately 1,600-m upstream of the mouth.

Factors limiting salmon production in Seabeck Creek include extremely low flows in the summer and impacts associated with high coarse and fine sediment transport levels (e.g., possibly egg scour and/or suffocation, reduced number of rearing and hold pools). Sediment loading in lower Seabeck Creek is primarily the result of bed and bank erosion. Erosion is prevalent along portions of the larger tributary. An average of over 4-m^2 of eroded bank was measured per linear meter of stream in one 100-m stretch. The streambed was substantially down-cut along this section and banks were eroding in response to the change in bed elevation.

Erosion has resulted in the filling of the lower streambed with sediment. Thirty years ago, the streambed was approximately 7 to 8-ft below the Stavis Bay Road Bridge (anecdotal report), whereas it is only about 3-ft below the bridge today. The absence of flow during the summer months may be at least partially the result of sediment deposition that converts surface flow to intra-gravel bed flow. Other factors may include increased withdrawal of groundwater as a result of development in the basin.

Stavis Creek

Stavis Creek is a 13.1-km^2 watershed located approximately 2.4-km west of Seabeck Creek. Its summer fish-bearing mainstem is nearly 8-km long (WDFW unpublished data). Additional summer fish-bearing habitat is found in South Fork Stavis Creek (2-km) and an unnamed left bank tributary to the mainstem (0.4-m). Much of Stavis Creek and its tributaries are incised within the steeply sloped surrounding hillside.

Of the four watersheds, Stavis Creek is the least developed. Most of the lands within the basin are private or DNR timberlands. Some rural residential development has occurred along ridge south of SF Stavis Creek. Principal impacts to the stream are related to sediment deposition from bank and slope failures, primarily in the mainstem. One slope failure located mainstem approximately 600-m upstream of the confluence of SF Stavis Creek is especially large. The slide, which occurred during the winter of 1999, was located on a steep slope that had been logged about 10-15 years earlier (Neuhauser personal comm.). The erosion scar from this slide was estimated at 550-m^2 (WDFW unpublished data). A tremendous amount of fine and coarse sediment was released in this slide which impacted spawning gravel down to the mouth of the stream, reduced rearing capacity, and affected benthic invertebrate (i.e., prey) populations. Although the greatest impacts occurred in the first two years following the slide, the fine sediments are continuing to be transported, to impact gravel downstream.

Germany/Mill/Abernathy Complex

Since smolt monitoring only began in 2001, less information regarding factors that influence freshwater anadromous production can be drawn from smolt production data. Nevertheless, by comparing the smolt production levels in these streams with others monitored in western Washington, we assess their relative productivity. Wade (2002) describes a number of limiting factors in the GMA monitoring complex. Smolt monitoring results can be used to evaluate these factors and help to prioritize their severity on juvenile production.

Average coho smolt production per square kilometer watershed area in the three GMA monitoring complex streams ranged from 89 in Abernathy Creek to 130 in Germany Creek (Table 5). These levels are substantially lower than those found in Stavis Creek (489 coho smolts/km^2) over the same two years. The low levels of coho production in the GMA streams likely relate to their higher stream gradients, which favor steelhead production, and possibly to low coho escapements, which are currently not measured. Wild steelhead smolt production per square kilometer of watershed averaged 20 in Mill Creek, 108 in Abernathy Creek, and 130 in Germany Creek. These levels are much higher than are observed in Stavis Creek over the same two years (4 steelhead smolts/km^2), a much smaller and lower gradient stream.

Wade (2002) identified a number of factors that limit production of anadromous salmonids in the GMA monitoring complex (Table 8). Fish passage at culverted stream crossings needs to be assessed throughout the basins. Splash damming historically occurred in the Mill and Abernathy drainages, which eroded channels, isolated the streams from their floodplains, and removed large woody debris. Streamside road construction further isolated streams from their floodplains and limited opportunities for off-channel habitats. Mass wasting in the upper watersheds has contributed substantial sediment loads to these channels resulting in the filling of pools and in reduced spawning habitat suitability. Poor riparian habitat condition in the basins may result in stream temperatures that limit salmonid production and reduce large woody debris recruitment. Aluminum toxicity has been identified as a concern in Mill and Cameron Creeks.

Given the steep nature of the Germany and Abernathy Creek watersheds, substantial hydraulic energy develops in these streams during storm events. The loss of floodplain connectedness and channel complexity is of particular concern in these basins since intact floodplains, woody debris, and other hydraulic controls would help to mitigate high flow impacts, stabilize coarse sediments, and provide additional rearing habitat. Removal of blockages may result in a measurable increase in juvenile production if habitat upstream of blockages is substantial.

Implementation

Fundamental to the IWM approach is the establishment of a set of overarching objectives, which provide the context for the application of ecological restoration and to which individual projects can easily be related. As the goal of most habitat restoration efforts for salmon and trout is to improve the survival of the fish through their entire period of freshwater residency, goals that relate to this outcome should be a component of the objectives. Individual restoration projects should collectively contribute to the attainment of the watershed level objectives. To determine whether this is occurring, projects applied at the reach scale should be nested within and related to the watershed-level objectives for habitat condition and fish populations. Such nesting creates an interconnectedness among projects that is critical to assessing the ultimate efficacy of the restoration effort. Following we provide an example of how such an effort could be structured to determine salmon response to the application of a watershed-level habitat restoration program.

Table 8. Habitat indicators for riparian condition, LWD, and % pools are ranked "poor" in large portions of all basins (Wade 2002).

Creek/habitat indicator	% of stream reaches		
	Good	Fair	Poor
Mill Creek			
Bank erosion	50	16	34
Fine sediment	53	37	11
Riparian condition	5	66	26
LWD	8	3	89
% Pool	0	11	89
Germany Creek			
Bank erosion	75	18	8
Fine sediment	53	36	11
Riparian condition	0	47	53
LWD	4	18	78
% Pool	0	1	99
Abernathy Creek			
Bank erosion	95	3	2
Fine sediment	7	39	55
Riparian condition	0	39	61
LWD	0	21	79
% Pool	1	8	91

Implementation of an IMW effort should begin with an assessment of the current condition of the watersheds to be monitored. There are a number of tools that are appropriate for this task including the Washington Watershed Analysis protocol. The information generated by this assessment will indicate the factors that are likely limiting fish production in the watershed. For example, if the watershed analysis identifies a lack of large wood in the streams in the basin, the hypothesis could be posed that lack of pool habitat is limiting available rearing space. An experiment to evaluate this hypothesis might involve deliberate addition of wood to channel segments and measurement of the change in pool habitat and summer and winter rearing populations at these sites relative to populations at untreated reaches (reach-level evaluation). However, even if this analysis indicates an increase in the number of fish rearing at treated sites, it does not provide information about the effect that these projects have had on the overall productivity of the fish population. In order to determine whether the wood addition has actually changed system productivity, rather than simply attracted fish to the treated reach that would have reared elsewhere, measures of watershed-level productivity are required.

In order to evaluate watershed-scale responses, the treatments (wood additions) need to be applied at enough locations so that a population response can be detected. If the initial hypothesis proves correct and rearing habitat does have a controlling influence on fish production in the watershed, the number of smolts produced or survival rate from egg to smolt should increase. The number of treatment sites required to detect a watershed-level response can be evaluated as wood-addition projects are successively implemented. Due to the expense and labor involved in wood additions to channels, application of treatments will occur over a period of years. Small increases in density of rearing fish at the reach level would indicate that watershed-scale responses would only be discernible when a large number of sites had been so treated. A very dramatic density response at the site level might suggest that changes in population should be measurable with treatment of fewer sites.

At a minimum, information on number of spawning adult fish and smolt output are required to evaluate watershed-level responses. Counting fences or weirs at the downstream end of a watershed provide the most accurate measure of adult salmon returning to spawn. This method is very accurate but labor intensive and provides no information about spawner distribution within the watershed. Counts of fish on the spawning grounds or mark-recapture estimates of spawning fish or carcasses conducted periodically during the time of spawning is not as accurate as counts at weirs in determining total number of fish but does provide data on distribution. The application of statistically valid techniques of reach selection and frequent, consistent surveys of each reach can improve the accuracy of estimates of spawner abundance. Such a method has been developed and implemented on the Oregon coast for coho salmon. Smolts leaving the WAU must be sampled by using some type of trap. Typical trap types include fences or weirs that capture all smolts exiting the WAU (although fences may become inoperable at high flows), or scoop or screw traps that capture a portion of the fish. Partial sampling traps are easier to maintain and can be utilized in channels too large for fences. However, these types of sampling devices require frequent calibration to determine the proportion of smolts being captured. With adult and smolt data it is possible to calculate the survival of the fish from spawning through smolting. The objective of nearly all salmon habitat restoration efforts (although often unstated) is to increase this value. Therefore, regardless of the methods selected to measure adult salmon and smolt abundance, these measures are critical to any comprehensive effort to evaluate fish response to restoration and must be included at all IMW sites.

Augmenting the smolt and spawner data with information on egg survival and the distribution, abundance and survival of juvenile salmon from emergence from the gravel through smolting can enable salmon response to individual restoration projects to be linked with response at the scale of the whole watershed. Capturing fish seasonally (spring, late summer, winter) by electrofishing, seining or trapping at multiple locations across the watershed would enable an estimate of fish distribution, abundance, growth rate, species, and age class composition. An alternative to capturing fish is a visual survey using an extensive sampling approach like Hankin-Reeves (Hankin and Reeves 1988) although this method does not provide information on fish species and size that is as accurate as methods that involve capturing fish, it is rapid and would enable sampling of the entire stream network in a WAU-sized watershed. A combination of the two approaches, a complete survey coupled with subsamples at selected sites where the fish are captured and measured, would provide the most complete information. The method selected will depend on how critical the measurement is, the characteristics of the site, and the resources available to be dedicated to obtaining the measurement.

Differential tagging of salmon captured during the sampling of different stream reaches and subsequent capture at the smolt trap could provide additional information on survival rates of fish rearing in different areas of the watershed and the effectiveness of individual restoration projects. Differences in survival among reaches or habitat types may provide an indication of key mortality factors operating in the river and aid in the identification of restoration efforts likely to have the greatest effect on salmon populations. There are numerous tagging technologies available. Passively induced transponder (PIT) tags, which are appropriate for larger fish (>70mm) have been used extensively on the Columbia River and enable individual identification of fish. Visible implant (VI) tags also can be used to identify individual fish although reading the tags is more difficult than with PIT tags. The injection of colored dyes or polymers into various transparent tissues of the fish enables determination of the location where a fish was tagged but cannot be used to identify individual fish. However, this type of tag may be very appropriate for addressing many of the questions related to restoration effectiveness.

The collection of data on fish populations must be coupled with information on the habitat attributes and climatic conditions. As fish are very sensitive to variations in flow, temperature and other factors that might not be directly influenced by restoration treatments, interpretation of the fish data can be enhanced by the collection of this information. At a minimum, a recording flow gauge is required at the mouth of the reference and treatment watersheds. In addition, if some of the restoration efforts are attempting to alter flow patterns, secondary flow gauges should be installed at the locations where these efforts are undertaken. A weather station collecting data on precipitation and air temperature should be located near the downstream end of the watershed. Water temperature also should be recorded year round at each gauging station and at all sites where one of the purposes of a restoration action is to alter water temperature. Instruments to record flow, weather and water temperature information data have improved dramatically in the last decade and costs have decreased. Thus, costs are reasonable for installing this equipment. However, maintaining the instruments and the database are labor intensive.

Data on habitat can be collected concurrently with fish sampling. These data are especially important at sites where restoration projects will be implemented. Habitat data can include physical characteristics of the channel (e.g., pools, riffles etc.), riparian area condition, levels of sediment deposited in pools and in spawning gravel, water quality (e.g., temperature, suspended sediment), nutrient levels and trophic productivity. The variables measured will depend on the objectives of the restoration actions. Projects designed to increase pool habitat will focus on the physical attributes of the channel while measures of nutrient levels and trophic production would be the most appropriate measures of a salmon carcass addition project.

The specifics of the biological, physical and habitat attributes measured in an IWM effort will vary depending on the questions being addressed. Regardless, the expense and effort required to obtain the necessary data to adequately evaluate the response of salmon to habitat restoration supports the notion of concentrating evaluation efforts in a relatively few locations. It will take a number of fish generations to get definitive results about the effectiveness of habitat restoration. However, by implementing these evaluations with clear objectives, careful consideration of experimental and statistical design, disciplined adherence to the experimental constraints at the treatment and reference sites, and patience, results can be produced that will greatly improve our ability to promote salmon recovery.

Example of an IMW Approach

The following illustrates an IMW approach to assess the effectiveness of a particular type of restoration project. The example provides an indication of how evaluation efforts can be nested at hierarchical spatial scales. This example details the elements required to assess a series of projects designed to reduce sediment input from a forest road system. Development of the evaluation approach requires four steps: (1) establishing objectives at each scale being evaluated, (2) collection of pre-treatment data, (3) implementation of the treatment, and (4) collection of post-treatment data. Each of these steps is applied to a series of interconnected experiments applied at each of three spatial scales: reach or project level, tributary watershed level, and basin level.

Objectives are required for each spatial scale from the reach level to the whole basin. These hypotheses should include both the physical habitat response and a related biological response. Road sediment can potentially affect salmon a variety of ways. Sediment settling on the streambed can clog spawning gravel, reducing survival of incubating eggs and fill pools, reducing available rearing habitat.   If a preliminary assessment of watershed conditions has identified sediment as a likely candidate to be limiting salmon productivity in the basin, then addressing this problem should result in increased survival of the fish from egg to smolting. Determining if the assessment is indeed correct requires that sediment delivery be changed sufficiently to produce a measurable response from the fish.

Experimental treatments to address this question would occur in a number of tributary watersheds within the treated basin. Initially, treatments would be concentrated in a single tributary watershed and the response compared with the untreated sites. Through time, treatments could progress from one tributary watershed to the next, provided that some of the tributary watersheds were maintained as references. Evaluations would occur at nested scales. At the reach level the effectiveness of individual projects on sediment production and proximate habitat condition would be evaluated. Assessments at the tributary watershed scale would provide an indication of the cumulative effect of the application of multiple treatments on sediment delivery and the resulting response of habitat condition and fish populations. Whether or not reductions in sediment production in the treated tributary watershed actually contributed to an overall increase in the production of smolts would be addressed at the watershed scale. The types of questions appropriate for each scale are summarized in Table 9.

Table 9. Types of monitoring questions and responses at appropriate spatial scales.

Scale	**Response Type**		
	Physical Response	Habitat Response	Biological Response
Reach	Do individual treatments reduce sediment delivery to the channel?	Does reduction in sediment input correspond to a reduction in sediment in streambed gravel and/or a reduction in deposited sediment in pools immediately downstream from the project area?	Does a reduction in sediment in streambed gravel correspond to an increase in egg survival at the project site?
Tributary Watershed	Does the application of multiple treatments result in lower suspended sediment export at the mouth of the treated tributary?	Is there an increase in the volume of pools in the treated watershed?	Are there increases in the density of rearing juvenile salmon in the treated watershed?
Basin	none	none	Is there an overall increase in the number of smolts produced or egg-to-smolt survival rate following application of treatments?

Pre-treatment data would be collected for a period of one or two years. No treatments would be applied at any of the sites during this time. Pre-treatment data would be collected on sediment production and delivery, habitat conditions in the stream and fish populations. Treatments would commence in year 2 and could extend over a period of several years if the plan is to sequentially treat multiple tributary watersheds. Treatments might include reconfiguration of drainage systems to divert ditch flow onto the forest floor, paving bridge approaches and utilization of harder surfacing materials.

Assessments implemented at the reach level would focus on the effect of sediment-reduction efforts implemented at a single location on sediment production and input to the channel. These site-specific assessments would not be conducted at every project site. Several representative examples of each project type would be assessed. Sediment input can be assessed with periodic grab samples or pump samplers deployed above and below the treatment location. The corresponding habitat attribute of interest at this scale would be the level of fine sediment in gravel or the amount of sediment deposited in pools. Measurements of these attributes would be taken annually at the project site and at a reference site in an untreated tributary watershed.

There are numerous methods for determining fine sediment levels in streambed gravel. Residual pool depth or closely spaced cross sections at pools could be used to determine changes in pool volume. The only relevant biological attribute at this scale would be the survival of eggs in the gravel before and after implementation of the sediment reduction measures and how this value compares with a nearby, physically comparable but untreated reach. There are a number of methods for measuring egg survival.

The next relevant spatial scale for this analysis is the tributary watershed. At this scale, a reduction in suspended sediment export at the mouth of the treated tributary would be the physical attribute most sensitive to the application of multiple sediment reduction treatments. Suspended sediment can be measured with grab samples or pump samplers at the downstream end of the tributary watershed. Changes in pool volume through time in the treated tributary watershed would be compared with changes in pool volume in a reference tributary watershed. Various survey techniques have been developed that are appropriate for extensive assessment of pool volume. Increased pool habitat and increased survival of eggs in the gravel should correspond to an increase in the abundance of rearing salmon in the treated tributary watershed. This response can be addressed by conducting an extensive survey of fish abundance (e.g., snorkel survey) in all areas supporting anadromous fish in the treated and reference tributary watersheds.

If sediment input to fish-bearing streams is truly a factor of consequence in determining the survival of salmon from spawning through smolting, an increase in smolt output should be detectable, provided that a sufficiently large area of the basin is treated. Changes in smolt output would be judged relative to smolt production from a reference basin. There are a number of ways to evaluate smolt response. Change in the total number of smolts produced per unit area or unit stream length from the basin where the treatments were applied relative to a corresponding measure from the reference basin is the most straightforward approach. With accurate counts of spawning adults, the smolt data can be used to generate estimates of egg-to-smolt survival. This measure may be more sensitive than simple smolt production as it does provide some ability to account for differences in the abundance of spawning adult salmon, which could be impacted by factors other than sediment levels. If sediment input was correctly identified as a factor limiting the production of salmon in the treated watershed, an increase in survival should become apparent as progressively larger areas of the basin undergo treatment.

Comparable approaches could be used to assess other types of restoration projects. Regardless of the type of restoration approach being applied, treatments and assessments must be applied in integrated manner that allows biological and physical responses at each spatial scale to be connected.

Project Phases and Tasks

Working with local and other partners, the project proposes to use a phased, long-term approach. Specific timeframes would result from monitoring and experimental designs that will address stated hypotheses.

Long term monitoring of smolts and returning adults at IMW sites is an essential characteristic of IMWs. Other IMW characteristics include the variety of habitat project types, land uses, and potential for public/partner support.

Before full implementation, a substantial scoping effort will be necessary. Three implementation phases are proposed, including:

- Phase 1 (year 1): scoping and pre-design work in initial candidate IMWs
- Phase 2 (year 2): final design development and initial startup
- Phase 3 (year 3+): full implementation

Phase 1 work would involve continuation of smolt sampling in two groups of initially proposed IMWs, which were sampled as part of the Index Watershed Monitoring. In addition, a statewide analysis of other candidates meeting IMW criteria would be performed.

Specific Phase 1 (2003-04) tasks include:

1. **Scoping and feasibility analysis in candidate IMWs**
   - Secure continuance of long term fish (juvenile and adult) monitoring in candidate IMWs.
   - In cooperation with local partners, assess habitat conditions, compile existing and collect new information as appropriate, identify linkages to past and potential future SRFB project activities and types.
   - Install basic climate and flow monitoring stations
   - Identify testable hypotheses, study design, linkages to project effectiveness monitoring, timeframes, and budget.
2. **Review and analysis of other IMW candidates and partnership opportunities in the state**
3. **Working with SRFB and other collaborators, recommend mechanism for long term implementation and coordination of IMW monitoring**
4. **Provide joint report of findings and recommendations**

Proposed Phase 2 (2004) and 3 (2005+) activities include:

Phase 2:

1. **Stage 1 implementation**
   - Review and adjust implementation approach and details as appropriate based on results from Phase 1 work.
   - Full implementation of long term experimental design plan in initial IMWs (data collection)
   - Develop timeline for analysis and reporting at key checkpoints associated with the experimental design
2. **Perform scoping feasibility and design work for high priority additional candidate IMWs recommended in Phase 1**
3. **Provide joint report of findings and recommendations**

Phase 3+:

1. **Stage 2 implementation**
   - Full implementation of long term experimental design plan and timeline in initial and any additional candidate IMWs

Costs (to be added)

Partners and Cooperators

Co-Leads:

Washington Department of Fish and Wildlife and Washington Department of Ecology

Partners:

Weyerhaeuser Company

NOAA Fisheries (Northwest Fisheries Science Center)

Environmental Protection Agency

Lower Columbia Fish Recovery Board Technical Advisory Committee

Hood Canal Coordination Council Technical Advisory Committee

Olympic Natural Resources Center/University of Washington (?)

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